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Welfare and growth impacts of innovation policies in a small, open economy

An applied general equilibrium analysis

Abstract:
We explore how innovation incentives in a small, open economy should be designed in order to achieve the highest welfare and growth, by means of a computable general equilibrium model with R&D-driven endogenous technological change embodied in varieties of capital. We study policy alternatives targeted towards R&D, capital varieties formation, and domestic investments in capital varieties. Subsidising domestic investments, thereby excluding stimuli to world market deliveries, generates less R&D, capital formation, economic growth, and welfare, than do the other alternatives, reflecting that the domestic market for capital varieties is limited. Directing support to R&D rather than to capital formation generates stronger economic growth, a higher number of patents and capital varieties, and a higher share of R&D in total production. However, it costs in terms of lower production within each firm, where presence of sunk patent costs and mark-ups result in efficiency losses. The welfare result is, thus, slightly lower.

Keywords: Applied general equilibrium, Endogenous growth, Research and Development

JEL classification: C68, E62, H32, O38, O41

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1. Introduction

The last two decades have seen the emergence of theoretical growth models in which technological change is endogenous. The product-variety model by Romer (1990) and the quality-ladder model by Aghion and Howitt (1992) are pioneer models and the starting point for many later contributions.[1] The major policy questions have been how an economy can sustain a positive growth rate and how innovation policy can enhance additional growth and welfare.

Our main contribution to the existing model literature is a focus on the small, open economy case, where a large part of the technological change comes from abroad, while aggregate models of Romer (1990) and descendants (see e.g. Jones and Williams, 2000; Alvarez-Pelaez and Groth, 2005; Steger, 2005) treat economies as closed. As in those models, we take into account that technological change results from profit-maximising R&D firms' output of patents that are purchased by capital producers in order to supply new varieties of capital equipments. Our model accounts for many of the central welfare arguments for subsidising innovation activities (see Jones and Williams, 2000), such as existence of external spillovers from previous R&D, love of capital variety in demand, and pro-competitive increases in output that counteract the inefficiencies due to imperfect competition in the capital variety markets (Markusen, 1981). However, increasing the number of firms and patents will, in isolation, also have external *negative* effects through reducing output within each firm and increasing aggregate fixed patent costs. These are arguments for discouraging innovations.[2] In addition to these features, we also take small, open economies' high reliance on externally given international prices, competition, and growth into consideration.

In order to conclude quantitatively on the implications of world market exposure, we apply a Computable General Equilibrium (CGE) model that can account for the complex economic settings within which innovation takes place. It captures interaction among markets, industrial differences in innovation rates, and market imperfections and policy wedges that potentially interact with innovation policies. The case of a small, internationally exposed economy is exemplified by the Norwegian economy. Previous applied macroeconomic models have not addressed similar cases. The applied model of Canada in Russo (2004) represents a closed economy. The pioneering CGE study by Diao et

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[1] In addition there is a substantial literature analysing the importance of an endogenous specification of technological change for climate-change analysis; see Goulder and Schneider (1999), Goulder and Mathai (2000), Popp (2004), and Otto et al (2005). The latter formulates a CGE model based on the product-variety models of Romer (1990) and Jones (1995).

[2] These impacts resemble, but are not the same as, the effects of creative destruction of existing goods and duplication externalities in patent races; see Aghion and Howitt (1992) and Jones and Williams (2000).

al. (1999) describes Japan as an open economy, but in several, important respects less reliant on the outside world than what is reasonable to assume for the Norwegian and similar small and open economies.

One main divergence from the model of Diao et al. (1999) is our treatment of the cross-country knowledge spillovers. In Diao et al. (1999) the impacts of international technology are channelled through the domestic R&D production. All spillovers from abroad enhance the productivity of R&D production with non-decreasing returns to scale. Own R&D, thus, plays a decisive role for economic growth. According to evidence from Norwegian firms, absorption of international spillovers through domestic R&D is far less potent (Cappelen et al., 2007). In our model, knowledge spillovers from abroad, which in the benchmark are calibrated to cause about 95 per cent of the Norwegian technological change, are absorbed through use of *all* resources, where investment goods that embody technological improvements caused by R&D are only one type of carrier. This feature of our model contributes to dampen the role of R&D-stimulating policies considerably.

The small, open economy focus also leads us to regard the interest rate as internationally given, in contrast to the closed capital market assumption in Diao et al. (1999). Export and import prices are, similarly, determined abroad. Capital varieties are both marketed abroad at given world market prices and sold in domestic markets characterised by monopolistic competition. Imports of other investment goods can substitute for the domestically produced capital varieties. Capital varieties are not exported in Diao et al. (1999), and the market power of each variety producer domestically is much larger than what is reasonable to assume in a small, exposed economy.

As productivity externalities are related to production and use of ideas and variety capital, we analyse three comparable policy alternatives stimulating these processes; the first is a subsidy of R&D production, the second is a subsidy towards formation of variety-capital, while the third is a subsidy towards domestic investments in variety-capital. In several countries, including Norway, firms that perform R&D can withdraw a limited amount of expenses each year as tax allowances or tax credit (Warda, 2005, Cappelen and Soland, 2006). The R&D subsidy approximates this kind of R&D support. The support to investments in variety-capital illustrates policies like traditional investment tax credits (Goulder and Summers, 1989; Bovenberg and Goulder, 1993), or recent popular implementation subsidies particularly used to promote new energy and environmental technologies. The policy alternatives are all financed by higher lump sum taxes.

The small, open nature of the economy implies, as expected, far smaller welfare and growth effects of innovation policies than in previous studies. The main impacts of adding small, open economy features are less influence of own R&D and less market power. In addition, increased capital supply is not reinforced by a lower interest rate, a mechanism that augments growth effects within closed economy models. On the other hand, world market exposure is the major impetus behind the positive welfare and growth effects we find. The improved competitiveness obtained within variety-capital production when subsidising R&D and capital formation, can be exploited by increasing deliveries to the export markets. Consequently, merely subsidising domestic investments induces but insignificant growth and welfare effects, as domestic demand is relatively inelastic. The positive effects on R&D and production of variety-capital are, thus, strongly dampened.

As opposed to the findings of Diao et al. (1999), subsidising R&D proves slightly welfare-inferior to subsidising formation of capital varieties, in spite of generating higher growth. Again, this is a result of the open economy features. The possibility of exporting variety-capital is essential for reaping high R&D productivity gains in case of capital subsidies. This result also illustrates the more general point that promoting economic growth is not necessarily welfare improving. It will depend on to what extent the reallocations that take place compensate or reinforce the externalities and price wedges that riddle the economy. Because the number of varieties increases more in case of R&D support, more crowding-out occurs of production and profits within each variety firm. Due to imperfect competition among the firms and fixed patent costs, these impacts dampen the productivity and welfare gains, in spite of somewhat higher spillover and love-of-variety effects.

Section 2 describes the CGE model and the simulation and calibration procedures. The policy effects and sensitivity tests are presented and discussed in section 3, while section 4 concludes.

2. The model

2.1 General features

The CGE model is a dynamic growth model with intertemporally optimising firms and households. The model gives a detailed industry structure with one R&D industry, one variety-capital industry (Romer's intermediates industry) and 16 final goods industries[3] (one public, 15 private; see Appendix A for a list). The final goods industries also deliver goods to each other according to the empirical

[3] The following industries are treated exogenously: the governmental sector, the offshore production of oil, gas, and pipeline transport, and ocean transport.

input-output structure. Growth is perpetuated through dynamic spillovers from the accumulated knowledge induced by R&D production, though with decreasing returns as in Jones (1995). R&D production creates new patents, and the monopoly right of each patent represents a fixed entry cost of a firm that produces a separate capital variety. Due to love of capital variety, the productivity of variety-capital within final goods industries increases with the number of variety firms.

The model fits a small, open economy and is applied for Norway. It gives a detailed description of the empirical tax, production and final consumption structures. Labour is perfectly mobile within the country, but immobile internationally. Other inputs, including investment goods, are internationally traded at given world market prices. Imports are modelled as imperfect substitutes for domestically produced goods (Armington function), while export deliveries are imperfect substitutes for home market deliveries (constant-elasticity of transformation (CET) technology). Both assumptions imply that the trade volumes are determined by the ratio of domestic to world market prices. The interest rate is also externally given. Financial savings are endogenously determined, subject to a non-ponzi game restriction that prevents foreign net wealth from exploding in the really long run. The exchange rate serves as numeraire.

In the following, the model structure is broadly described. The public sector, which collects taxes, distributes transfers, and purchases goods and services from the industries and abroad, is suppressed in the exposition, as are the transfers and tax/subsidy wedges. Appendix C illustrates how the studied subsidy schemes are implemented. An extended presentation of the equations determining firm and household behaviour is found in Appendix B. See also Bye et al (2006)[4] for a complete model documentation.

2.2 Industries

Final goods industries

We assume that all firms within the final goods industries are identical and take the prices as given in the factor and goods markets, domestically as well as abroad. The technology of production in each firm is given by (subscript *i* denoting firm *i* is suppressed):

(1) $$\left[\left(X^{H}\right)^{\rho}+\left(X^{W}\right)^{\rho}\right]^{1/\rho}=\left[f\left(L\tau,K_{V}\tau,K_{M}\tau,V\tau\right)\right]^{s}.$$

[4] Available at http://www.ssb.no/emner/10/03/doc_200611/doc_200611.pdf.

L, K_V, K_M, and V represent inputs of labour, variety-capital, other, ordinary capital, and intermediates. The entire nested input factor tree of Constant Elasticities of Substitution (CES) aggregates is presented in appendix B, figure B.1. τ denotes exogenously driven factor productivity change from abroad. It is assumed to be factor and industry neutral and to increase the efficient input of each factor. X^H and X^W are deliveries to the home and world markets, respectively. These markets are assumed segmented through a CET technology, where the transformation elasticity $\rho > 0$ implies costs of diverting deliveries between the two markets. This, together with decreasing returns to scale, i.e. $s < 1$, avoids complete specialisation of production of tradeables.

Each firm has perfect foresight and maximises the present value of the after-tax cash flow. By assuming $s=1/\rho$ we obtain separability between the export and home market supplies, which are set according to first-order conditions that equate marginal revenue with marginal costs for deliveries to the respective markets; see Holmøy and Hægeland (1997). The world market price is exogenous while the price in the domestic market is determined by market equilibrium, given the cost structure.

The input of capital varieties, K_{Vi}, is represented by so-called Spence-Dixit-Stiglitz (love-of-variety) preferences for the variety-capital composite K_V:

$$(2) \qquad K_V = \left[\int_0^R \left(K_{Vi} \right)^{(\sigma_{kv}-1)/\sigma_{kv}} di \right]^{\sigma_{kv}/(\sigma_{kv}-1)}.$$

R is the accumulated number of capital varieties (and firms in the variety-capital industry), and σ_{kv} is the uniform elasticity of substitution applying to all pairs of capital varieties. The more varieties, the higher is the variety-capital productivity within final goods industries.

Production of R&D services

The R&D industry delivers new patents to domestic capital variety firms that wish to enter the variety-capital industry.[5] The production of new patents in one time period, X_R^H, is given by:

$$(3) \qquad X_R^H = [R]^{s_1} \left[f\left(L\tau, K_M\tau, V\tau \right) \right]^s.$$

[5] The model does not disregard international trade in ideas, but trade in ideas is encompassed in the trade of capital varieties (see below).

The same nested CES production technology as for the final goods industries applies, apart from that the R&D industry does not use the differentiated capital composite, K_v.[6] As for the final goods production, the exogenous change in τ captures absorption of international technological change. In addition, productivity is enhanced by endogenous domestic spillovers that are freely accessible by all incumbent and potential patent producers. These originates from the accumulated stock of knowledge, R, embodied in patents, so that $R = R_{-1} + X_R^H$. s_1 denotes the elasticity with respect to these domestic spillovers.

All firms within the R&D industry are identical and take the prices as given in factor and output markets. Each firm has perfect foresight and maximises the present value of the after-tax cash flow. This gives first-order conditions that equate domestic prices with marginal costs.

Production of capital varieties

Each capital variety-producing firm buys one patent from the R&D industry as a fixed establishment cost, and produce one capital variety based on the patent. We assume that the cost structure is identical for all the firms within the industry. As for the R&D industry, we exclude variety-capital as a production factor. We allow for deliveries both to the domestic and the export markets with the same assumptions about separability in the cost structure between deliveries to the two markets as for the final goods industries. Technological change from abroad is accounted for through the τ's, and we, therefore, do not allow for additional productivity growth through import of capital varieties. However, other ordinary machinery capital, which is a relatively near substitute, is imported; see the nested CES structure in Appendix B, figure B.1.

The variety firms have market power in the domestic market, but exhibit no market power in the export market, where prices are externally given. This is a reasonable assumption for a small and open economy.[7] Each firm has perfect foresight and maximises the present value of the after-tax cash flow. This gives the following first-order conditions for deliveries to the world and home markets, X_{ki}^W and X_{ki}^H:

(4) $$P_k^W = \frac{c}{s}\left(X_{ki}^W\right)^{\frac{1-s}{s}}$$

[6] This choice is made to avoid cumulative multiplicators of the love-of-variety effect.

[7] Section 3.4 provides sensitivity analyses with endogenous world market price for capital varieties.

(5) $$P_{ki}^{H} = m_{ki} \frac{c}{s} \left(X_{ki}^{H} \right)^{\frac{1-s}{s}} .$$

For deliveries to the export market the world market price P_k^W equals marginal costs where *c* denotes the unit input costs. In the home market, the monopoly price of capital variety *i*, P_{ki}^H, is set as a mark-up, m_{ki}, on costs. $m_{ki} = \frac{\varepsilon_{ki}}{\varepsilon_{ki} - 1}$, and ε_{ki} is the domestic demand elasticity for capital varieties. The variety composite is used as input in the final goods industries. The mark-up factor is independent of *i*, since the demand elasticity is equal to the constant elasticity of substitution between the different varieties (see e.g. Bye et al., 2006). This, together with the assumption of equal production and cost structure in each firm and the monopoly-pricing rule, implies that the price in the domestic market is equal for all the capital varieties, and each variety is produced in equal quantities.

From the value maximisation of the representative firm, while using the fact that profit is equal for all firms, $\pi_{it} = \overline{\pi}_t$, the entry condition for each capital variety-producing firm can be deduced:

(6) $$P_{R0}^{H} = \int_0^\infty e^{-rt} \left(\overline{\pi}_t \right) dt .$$

P_{R0}^H is the fixed entry cost of buying one patent from the R&D industry in period 0. Firms are entering the capital variety industry until the representative firm’s total discounted net profit is equal to the entry costs. In each period, new patents are produced and new firms will enter the variety-capital industry. The entry condition determines the price of a new patent in each period. Given that a firm has entered, the first-order condition in eq. (5) determines the domestic price of the capital variety for given marginal costs and demand.

2.3 Consumer behaviour

Consumption and saving result from the decision of an infinitely lived representative consumer that maximises intertemporal utility with perfect foresight. The consumer chooses a consumption path subject to an intertemporal budget constraint that requires the present value of consumption not to exceed total wealth (current non-human wealth plus the present value of labour income and net transfers). Labour supply is exogenous. We assume that the consumer's rate of time preferences equals the exogenously given nominal interest rate for the entire time path. Total consumption is allocated across 10 different goods and services according to a nested CES structure. The structure is given in figure B.2 in Appendix B.

2.4 Equilibrium conditions

The model is characterised by equilibrium in each period in all product markets and the labour market. Intertemporal equilibrium requires fulfilment of two transversality conditions: the limit values of the total discounted values of net foreign debt and of real capital, respectively, must both be zero. The model is characterised by a path-dependent balanced growth path solution (or steady state solution), see Sen and Turnovsky (1989) for a theoretical exposition. This implies that both the path and the long-run stationary solution differ between simulated scenarios.

To ensure a long-run *balanced growth path*, the following conditions must be fulfilled: 1) The rate of technological change for each input factor in each industry must converge to the same rate, g^s, so that each industry grows at the same rate. 2) The growth in per capita consumption equals the same rate, g^s. 3) The population growth rate is constant. Along the transitional path the growth rate may vary. See Bye et al (2006) for further details.

A balanced growth path also requires that the following equation is fulfilled:

$$\left[\frac{(1+\theta)}{(1+r)\big/(1+p)}\right] = \left(1+g^s\right)^{-1/\sigma_d} \tag{7}$$

θ is the rate of time preferences, r is the nominal interest rate, p is the growth rate of the consumer price index, and σ_d is the intertemporal elasticity of substitution. Together with equation (7), the transversality condition regarding net foreign debt is fulfilled when the consumer finds the optimal level of consumption, given the intertemporal budget constraint and the transversality condition. Correspondingly, the transversality condition for the value of real capital is a restriction on the determination of net investments by firms.

2.5 Data and parameters

The model is calibrated to the 2002 Norwegian National Accounts. The elasticities of substitution in the production technology range from 0.15 at the upper part of the nested tree to 0.5 further down in the nested tree structure, see Appendix B, figure B.1, and are in the range of empirical findings (Andreassen and Bjertnæs, 2006). We have less empirical foundation for the substitution possibilities within the composite of variety-capital and ordinary machinery capital. We assume a relatively high substitution elasticity of 1.5, while the elasticity between the different capital varieties is expected to be even higher and set to 3.0, giving a mark-up factor of 1.5 for the domestic price of capital varieties.[8]

The elasticities of scale are equal to 0.83 in all industries, and fit econometric findings of moderate decreasing returns to scale in Norwegian firms (Klette, 1999). The scale elasticity is at the lower end of the estimates by Klette (1999), but is chosen in order to avoid unrealistic industrial specialisation patterns.[9] This implies that the elasticities of transformation between domestic and foreign deliveries are equal to 5. The elasticities of substitution between domestic products and imported goods are assumed equal to 4.[10] The elasticity of scale related to previous knowledge is equal to 0.5, in order to ensure decreasing spillover effects of the knowledge base, supported by both theoretical and empirical findings (see Jones, 1995; 1999; Leahy and Neary, 1999).

2.6 Exogenous assumptions and balanced growth

The exogenous growth factors are assumed to grow at a constant rate. In most cases rates are set in accordance with the average, annual growth estimates in the baseline scenario of Norwegian Ministry of Finance (2004) that reports the governmental economic perspectives until 2050. In the governmental perspectives, total factor productivity growth is entirely exogenous and valued at, on average, 1.0 per cent annually. Our model distinguishes between an exogenous and an endogenous component. In line with empirical findings; see e.g. Coe and Helpman (1995) and Keller (2004), we ascribe 95 per cent of the long-run domestic total factor productivity growth to exogenous diffusion of international technological change.[11] The long run in this context is 50-70 years from now, where the reference path obtains a stable growth period. The assumed 5 per cent growth resulting from domestic R&D in this period forms a basis for calibrating the 2002 level of knowledge, R_0, which together with

[8] This is in line with the Jones and Williams (2000) computations that exclude creative destruction (similarly to our model). Numerical specifications of Romer's Cobb Douglas production functions, as in Diao et al. (1999), Lin and Russo (2002), and Steger (2005), result in far larger markups. Markups of 1.5 are nevertheless in the upper bound of econometric estimates (Norrbin, 1993; Basu, 1996). Our main motivation for staying in the upper bound area is that we model industrial R&D as outsourced to a separate R&D industry. Thus, R&D costs are ascribed to this R&D industry, whereas the marginal costs of final industries exclude this part of the costs. This deviates from typical regressions of markups, where marginal costs include all observed costs, including industrial R&D costs. Another, more technical, reason for our relatively high markups is that the capital varieties represent a small share of machinery capital and thus of total inputs. This, in isolation, drives the markups required to calibrate the model upwards.

[9] Because $\rho=1/s$, a larger elasticity of scale will imply a larger elasticity of transformation between domestic and foreign deliveries, $\sigma=1/(1-\rho)$. If the elasticity of scale is close to 1 (constant returns to scale), the elasticity of transformation will be very high, implying practically no dispersion between domestic and foreign deliveries.

[10] These parameters values correspond to similar parameter values in the MSG6-model, a traditional applied CGE model for the Norwegian economy, Heide et al (2004),

[11] This lies in upper bound of estimates for small, open countries like the Norwegian. We choose that, as several mechanisms believed to drive domestic innovations are excluded from the model, like basic, governmental research, endogenous education, and learning-by doing.

the remaining parameters of the model determines the productivity growth from domestic knowledge accumulation. The population growth is set to 0.4 per cent annually, in accordance with the expectations in Norwegian Ministry of Finance (2004). Exogenous activities, like public consumption and output, are also set in accordance with the governmental perspectives. The exogenous levels of offshore investments and oil and gas exports result from a smoothing of their expected present values in the governmental perspectives. The smoothing is made to account for the economic significance of the Norwegian oil and gas resources without introducing another source of dynamics into the growth path.

World market prices are assumed to increase 1.4 per cent annually. This is in the lower range of exogenous price growth estimates in the governmental perspectives. The export price of capital varieties is assumed to rise even more slowly, in line with the domestic price increase of 0.6 percent annually on average for the capital varieties. Lower-bound estimates are chosen to let exogenous inflationary impulses be more in line with internal impulses, which are dampened by the consumption-smoothing features of the model. This provides us with endogenous developments of the delivery ratios between the export and domestic markets that are more in line with those of the governmental perspectives. The international nominal interest rate is 4 per cent. All policy variables are constant in real terms at their 2002 levels.

In the long run, i.e. 50-70 years from now, the stable GDP growth rate of the reference path amounts to 1.5 percent annually; that of consumption is 0.5 percentage points lower, as net export is increasing more in this period. The growth rates of the activities driving the domestic growth impetus, R&D and variety-capital production, are relatively high (3.5 and 3.1 per cent annually). As the endogenous growth is assumed to asymptotically approach zero, in line with the non-scale growth assumption (Jones, 1995), the growth in steady state will only depend on exogenous drivers. For technical reasons, we have set all exogenous and endogenous growth drivers to zero in the far future (after about 100 years). This ensures that the economy is eventually on a balanced growth path (steady state) and that this growth path, with zero growth, satisfies the transversality conditions described in section 2.4. In particular, equation (7) then implies that $r=\theta$ at all points in time.[12]

[12] We have tested the significance of this assumption by varying at what time the zero growth is imposed. The relative effects of the different policy analyses appear independent of this timing, as do the growth rates within the stable period. Only the durability of the stable period is affected.

3. Policy analyses and numerical results

We explore the welfare and growth outcomes of innovation incentives. by simulating three distinct policy alternatives: an R&D subsidy, a subsidy towards capital formation, and a subsidy towards domestic investments in variety-capital. All the policy alternatives are implemented in the first year of simulation and kept constant during the rest of the simulation period; see Appendix C for the modelling of the subsidies. To make the three distinct policy alternatives comparable, the ad valorem subsidy rates are dimensioned so that the annuities of the subsidy amounts become equal.[13] The public revenue annuity is approximately 250 million , which is about 1.5 times larger than today's value of the Norwegian tax credit system for R&D expenses. The resulting ad valorem subsidy rates for the three subsidy schemes will depend on their subsidy bases; see table 1.

We report the long run effects 70 years from now, when the economy has obtained stable growth rates and before the endogenous growth is emptied out. Both long-run consumption and the discounted consumption over all periods, including the transition and balanced growth path, are given. The latter measures welfare. The effects of the different policy alternatives, mostly measured as deviations from the reference path, are given in table 1.

[13] See Bye et al. (2006) for the intertemporal solving algorithm.

Table 1. Policy alternatives, long run effects, percentage deviations from the reference path

Policy alternative	R&D subsidy	Capital subsidy	Investment subsidy
Subsidy rate*	**5.20**	**1.25**	**4.14**
Price of patents	-8.38	-0.15	-0.33
Production of patents	45.40	23.27	5.86
Price of capital varieties	-0.97	-1.23	-3.51
Production of variety-capital	17.30	11.79	2.81
Domestic	13.53	7.24	4.47
Export	18.69	13.46	2.22
Production in each variety firm			
Domestic	-8.28	-3.77	1.45
Export	-4.11	1.80	-0.72
GDP	1.90	1.17	0.27
GDP, growth rate**	0.07	0.04	0.01
Total consumption	0.22	0.28	0.00
Consumer price index	0.74	0.52	0.12
Composite price of capital varieties	-10.36	-5.82	-3.79
Composite used in ord. machinery prod.	14.40	8.04	4.68
Nominal wage rate	1.43	0.94	0.25
Total export	3.11	2.25	0.35
Total import	2.81	2.08	0.37
Private R&D/GDP***	1.9	1.6	1.4
Welfare	0.32	0.33	0.02

*The exogenous, constant rate in the policy scenarios (per cent)

** Absolute deviation from reference path

*** Share in the policy scenarios (per cent)

3.1 R&D subsidy

Effects on production of R&D and variety-capital

The subsidy given to production of new patents amounts to an ad valorem rate of 5.20 per cent, and has the direct effect of shifting marginal costs of R&D production downwards. For a given patent price, supply increases, and for the capital variety industry to be able to absorb more patents, the price must fall. The marginal willingness to pay for patents is determined by the discounted profit for the last new firm entering the capital industry, and it falls as a result of reduced production and, thus, profit within each firm. The marginal costs of the R&D firms will be further shifted downwards as a result of dynamic, positive spillover effects from the accumulated knowledge stock, and this reinforces the partial market dynamics. In long-run equilibrium, the R&D production increases considerably, by

45.40 per cent. In terms of the R&D intensity, this increase meets the expressed goal of the Norwegian government of increasing the private R&D/GDP ratio to 2 per cent, from a long-run ratio of 1 per cent in the reference scenario. The profit within each capital variety-producing firm is reduced and is mirrored by the patent price fall of 8.38 per cent compared to the reference. The number of capital variety firms increases by 17.30 per cent.

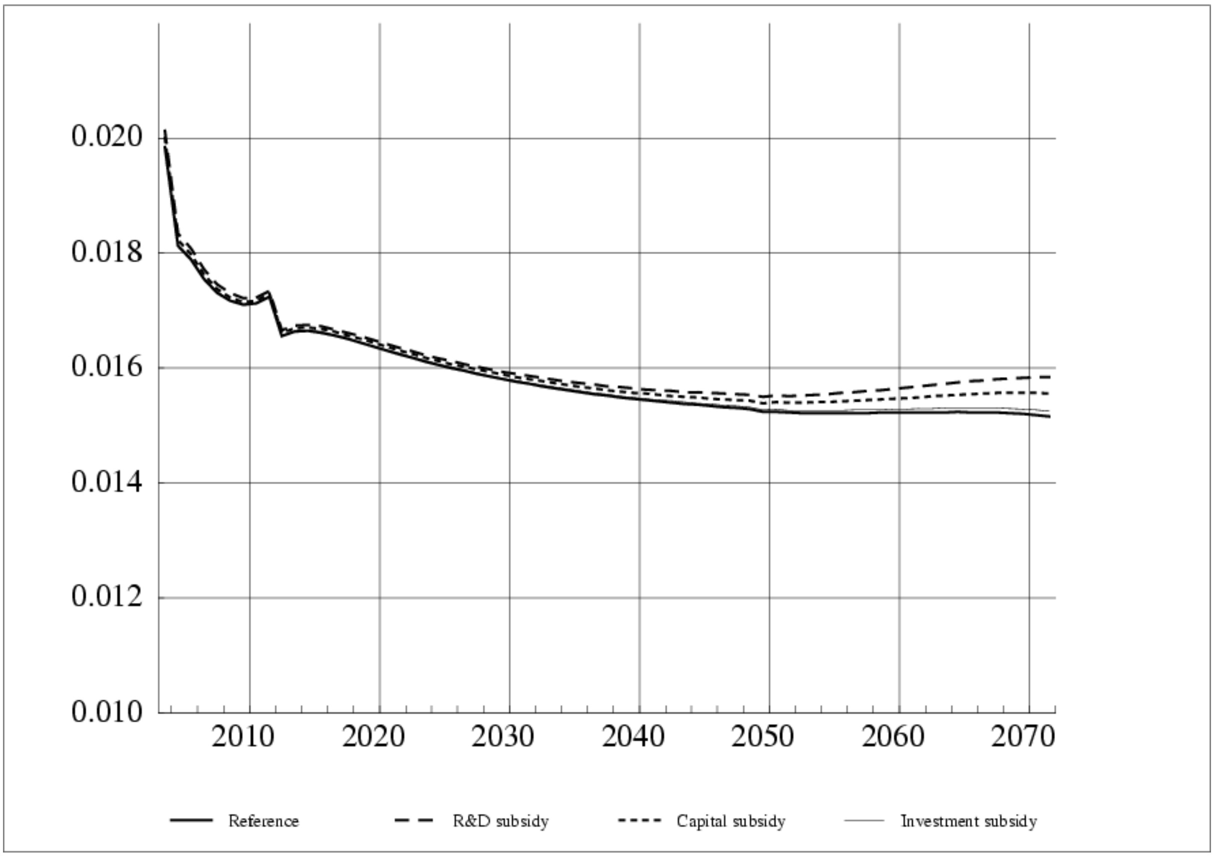
In the domestic market for variety-capital, the demand faced by each variety firm shifts downwards as the number of varieties increases. This contributes to reduce both the mark-up price and the domestic production of each variety. In the long-run equilibrium, the domestic prices of capital varieties fall by 0.97 per cent and domestic deliveries from each firm by 8.28 per cent. Also export deliveries fall, though less, since the export prices are unchanged. Even though export from each firm falls by 4.11 per cent, the aggregate export market supply of variety-capital increases markedly. Due to the increased number of firms, exports increase by 18.69 per cent. In the domestic markets, where there is love of capital variety in demand, increased number of patents will increase the efficiency of using the capital composite and amplify the price reduction. In long-run equilibrium, the domestic price of the capital composites falls by 10.36 per cent, and demand is stimulated. The use of the composite does for instance increase by 14.4 per cent for the industry producing other, ordinary machinery goods.

Reallocation, growth, and welfare

The results reported above for the innovative industries producing R&D and variety-capital, as well as results for all remaining industries, are influenced by indirect changes in all factor markets. The subsidies increase the demand in both the R&D industry and the variety-capital industry for other inputs, like labour, intermediates and other investment goods. This, combined with higher final consumption, contributes to a rise in all other factor prices than variety-capital. The wage increase in the long run amounts to 1.43 per cent and is a result of both higher demand and increased productivity of labour due to higher production of R&D and capital varieties. For most of the remaining products the unit costs of production increase, and export and home market deliveries fall, both in the short and long run. One exception is home market deliveries of other capital goods like ordinary machinery capital, buildings and constructions that increase somewhat due to the higher demand from the innovative industries.

Growth is negative for the non-innovative part of the economy. This is true in spite of the enhanced variety-capital productivity resulting from more varieties. Nevertheless, the growth in GDP rises, because the expansion of the R&D and variety-capital industries dominates. The economy reaches a new and higher stable growth rate; see figure 1. Long-run GDP increases by 1.90 per cent and the growth rate is 0.07 percentage points higher.[14]

Figure 1. The development in GDP growth rates; reference and policy alternatives; percentage points



Welfare, measured as discounted consumption in each period, increases by 0.32 per cent. The main contributions to the welfare gain originate from the increased R&D and variety-capital production through the following two channels: the positive spillover effect in production of patents of a larger knowledge stock, and the positive love-of-variety effect in the demand for variety-capital as the number of capital varieties increases. These are counteracted by two negative welfare contributions: the welfare loss through lower production within each monopoly firm producing capital varieties, and the negative contribution from higher overall fixed entry costs in terms of patent expenditures (for a given patent price).

[14] Domestic gross product, GDP, includes return from the factors labour, capital and knowledge. GDP is measured exclusive of the exogenous, offshore petroleum production.

In the presence of various distortions in the economy, other reallocations may also affect efficiency and welfare. One negative contribution to welfare stems from the fact that savings fall, in spite of considerable capital accumulation, in particular of variety-capital. As opposed to closed economy models, national savings are separated from capital investments by the possibility of financial saving and borrowing. We find a higher rise of consumption during the first 40 periods than in the long run. This reflects a considerable fall in financial savings that renders total savings in the transitional path lower than in the reference. As capital income taxation drives a wedge between private and social returns to capital, savings are too low from an intertemporal efficiency point of view, and the reduction of savings reinforce this inefficiency.

Though different analytical designs exclude accurate comparisons, it is clear that the quantitative effects on growth and welfare of subsidising the R&D industry are much smaller in our analysis than in applied studies of larger and more closed economies, like in Diao et al. (1999) and Russo (2004). A main explanation is our allowance for a dominating role of external, international productivity growth, which in the reference path accounts for 95 per cent of domestic growth. In contrast, domestic processes account for all TFP growth in the previous CGE studies, as in existing theoretical contributions. In addition, the applied analyses referred to assume stronger love of capital variety, which reinforces productivity gains of patent production. Their results are also influenced by endogenous and falling interest rates that spur savings and investments. Diao et al. (1999) include non-decreasing spillover effects of knowledge accumulation, which contributes to their welfare and growth effects.

3.2 Capital subsidy

Effects on production of R&D and variety-capital

A subsidy offered to all the producers of capital varieties, independent of whether the firms already exist or wish to enter, is equivalent to a downward shift in their cost curves. The annual ad valorem subsidy rate to production comparable with the R&D subsidy above is 1.25 per cent. These cost shifts explain the increase in the intra-firm deliveries to the export markets, which in the long term amount to 1.80 per cent. In the domestic markets, the cost reductions are reflected in a 1.23 per cent lower variety price. However, in spite of cost reductions, the intra-firm deliveries are 3.77 per cent lower in the long run than in the reference path. This is explained first of all by a simultaneous downward shift in the demand facing each variety producer as a consequence of an increased number of competing firms. The entry of new firms is a result of changes in the patent market. First, higher profits for the capital variety producers shift the demand for new patents upwards. Second, the stimulation of patent production induces spillovers that bring about dynamic productivity gains within firms. Both these shifts stimulate long-run patent production, which increases by 23.27 per cent in the new equilibrium. This is, however, only 60 per cent of the R&D expansion obtained in the R&D subsidy alternative, while the long-run private R&D/GDP ratio is 1.6, which is 85 per cent of the ratio in the previous alternative. In long run equilibrium, the price of the patent is reduced by 0.15 per cent, reflecting that the productivity gains of the spillovers in the long run dominate the price pull of higher willingness to pay among variety firms.

As for the R&D subsidy alternative, the aggregate supply of variety-capital increases and, again, it is almost entirely explained by more firms. The output increase is less pronounced than in the former alternative. The sum of exports from all firms increases by 13.46 per cent, or about 70 per cent of the R&D subsidy result. The efficient supply of variety-capital in the domestic market, which includes the positive love-of-variety impact, increases. For example, the deliveries to the industry producing ordinary machinery goods increase by 8.04 per cent. The output rise reflects a reduction in the domestic price of the composite of 5.82 per cent. However, this fall is not more than 50 per cent of the fall obtained in the R&D subsidy alternative. This is primarily explained by weaker productivity gains within patent production, and also by weaker love-of-variety effects when number of varieties increases less.

Reallocation, growth, and welfare

As for the R&D subsidy, stimulating the production of capital varieties through a direct capital subsidy increases the demand for other inputs from the innovative industries producing variety-capital and R&D. But since their expansion is weaker in the present policy alternative, the factor prices and unit costs increase less. The wage rate increases by 0.94 per cent. The reallocations, and subsequent productivity effects, are qualitatively similar, but weaker, than in the R&D subsidy case. Total gross product increases by 1.17 per cent due to the value added increase in the innovative part of the economy. The growth rate of GDP is 0.04 percentage points higher than in the reference path, which is lower than in the R&D policy alternative; see figure 1.

In spite of weaker growth effects, the welfare gain of 0.33 per cent compared to the reference path is slightly higher than in the former alternative. It reflects a higher consumption in the long run. A significantly smaller drop in intra-firm deliveries to the home markets is an important explanation. This reallocation contributes to improved welfare because of the mark-up pricing domestically. In his welfare study of long-run balanced growth paths, Steger (2005) also emphasises imperfect competition in the capital markets as a highly significant distortion. However, during the transition path we find that consumption is far less affected. The higher efficiency contribution from more intra-firm production in variety firms is nearly offset by markedly weaker short-run productivity gains from both the R&D spillovers and the love of capital variety. This difference between the two alternatives is less pronounced in the later periods, due to the diminishing returns to the scale of R&D. The discrepancy we find between short and long run effects points to the importance of not disregarding the transitional path in welfare considerations.

The intertemporal development of consumption reflects that total savings are higher in this alternative than in the R&D subsidy alternative. This means a smaller intertemporal efficiency loss related to the capital income taxation. Imports develop more slowly in the transition path. This is most prominent in case of investment good imports, which is driven to a large extent by the demand from R&D and variety production. As a result, the economy builds up a lower level of net foreign debt than in the R&D subsidy alternative, and consumption is less crowded out by a need to export in the long run in order to serve debt.

3.3 Subsidy to domestic investments in variety-capital

Effects on production of R&D and variety-capital

A subsidy offered to domestic purchases of variety-capital will act similarly to a subsidy towards the part of the capital production that is destined for the domestic markets. While this distinction is not topical in previous analyses of closed markets, our international market setting allows us to distinguish between this alternative and the former alternative, where also capital supplies for the export market are subsidised. The subsidy, implemented as a rate of 4.15 per cent of the domestic purchaser price, is equivalent to a downward shift in the costs of domestic deliveries for both existing producers and possible new entrants. As a result, the domestic variety price decreases by 3.51 per cent in the long run, which is significantly more than in the former alternative where the same subsidy amount covers all deliveries irrespective of destination. The intra-firm deliveries to the home markets increase somewhat, as opposed to the former alternative, where they were crowded out by a larger number of firms. However, a larger home-market production within firms comes at the expense of intra-firm exports, which falls by 0.72 per cent. Also in this policy alternative, lower costs and higher profits for the capital variety producers shift the demand for new patents upwards, though not to the same extent as in the former alternatives. The production of patents increases and induces dynamic spillover effects and downward cost shifts for the variety producers. In the long run, R&D production increases by 5.86 per cent. The long-run price of patents also falls, by 0.33 per cent, primarily explained by the dynamic spillovers.

Similarly to the other two policy alternatives, this subsidy stimulates aggregate supply of variety-capital, both at home and abroad. But the output effects are smaller, because the number of firms increases less. Export production increases by 2.22 per cent, only. The increase indicates that in spite of reduced exports from each variety firm, there is a positive international competitiveness effect for the industry at large, due first of all to the reduced patent costs. At home, the industry's deliveries increase more. In efficiency units, i.e. inclusive of the love-of-variety effects, the deliveries to the ordinary machinery industry do, for example, increase by 4.68 per cent. This reflects a domestic price reduction of the variety-capital composite of 3.79 per cent.

Reallocation, growth, and welfare

As with the other policy alternatives, a domestic investment subsidy increases the demand for inputs in both the variety-capital industry and the R&D industry. Factor prices increase, implying higher production costs for all industries. Output reductions occur within all industries except R&D, variety-capital, and ordinary capital production, but the effects are smaller than in the other policy alternatives. The growth and total welfare effects are negligible. Growth first of all relies on R&D expansion, which is small in this alternative. Also the welfare gains released in the former alternatives largely relate to R&D expansion. Relatively less R&D spillovers and love-of-variety effects in this investment subsidy alternative reduce the welfare gain. These effects are not sufficiently compensated by a favourable stimulation of domestic deliveries from each firm, which tend to increase efficiency within the imperfectly competitive markets. As opposed to models with no entry (see e.g. Hertel, 1994 or Greaker and Rosendahl, 2006 for a recent, numerical application), such pro-competitive effects are not obtained within the other policy alternatives, even though domestic deliveries increase. When R&D or variety production are subsidised, entry in the variety-capital industry crowds out intra-firm output and is, in this sense, anti-competitive.

All in all, subsidising only domestic investments induces but insignificant growth and welfare effects, as domestic demand is relatively inelastic. The positive effects on R&D and production of variety-capital are, thus, strongly dampened.

3.4 Sensitivity analyses

The quantitative estimates of growth and welfare effects rely on the chosen parameters. In addition, our computations indicate that the possibility of expanding production by exploiting the world markets for variety-capital plays a crucial role. We have performed sensitivity analyses regarding the spillover parameter in the R&D production function, the mark-up factor in the markets for capital varieties, as well as in the world market assumptions with respect to variety-capital demand.

Changes in spillover parameter and mark-up factor

We test the effects on the policy results of a 2 per cent increase/decrease in the spillover parameter s_1 and the mark-up factor m_{ki}. The results from the sensitivity analyses are measured as percentage deviation from the base policy scenarios and given in table 2. Reducing the spillover parameter lowers the effect on growth and welfare compared to the base policy alternatives. The same is the case with lower mark-up factor. The results are symmetric such that increasing the spillover parameter and the mark-up factor both contribute to higher economic growth and welfare.

The main conclusion to draw from these tests is that the rankings of the policy scenarios are robust to the parameter changes; see table 2. In particular, in all tests the capital subsidy continues to be slightly welfare-superior to the R&D subsidy. In table 2, only long-run effects on consumption are reported. The short-run effects are nearly similar to the base policy scenarios, so that the long-run results are representative for the changes in welfare.

Table 2: Sensitivity results of changing the spillover parameter and the mark-up; percentage deviation from the base policy scenarios, long run effects

Policy alternatives	R&D subsidy				Capital subsidy			
Senstitivity test	Spillover		Mark-up		Spillover		Mark-up	
Parameter value	**0.49**	**0.51**	**1.47**	**1.53**	**0.49**	**0.51**	**1.47**	**1.53**
GDP	-0.51	0.53	-0.34	0.33	-0.43	0.47	-0.31	0.30
GDP, growth rate*	-0.03	0.03	-0.02	0.02	-0.02	0.03	-0.01	0.02
Long run consumption	-0.04	0.04	-0.05	0.05	-0.04	0.04	-0.05	0.05

* Absolute deviation from the base policy scenarios

Changes in export market assumptions for variety-capital production

The test of the world market assumptions is performed by letting the export price of variety-capital evolve similarly to the domestic price. The share of deliveries destined for the world markets will be unaltered in this alternative.

The sensitivity analyses confirm that the small and open economy benefits significantly from reallocations of deliveries towards export markets for variety-capital. When such reallocations are prohibited through equal percentage developments in prices and deliveries within the home and world markets, productivity gains cannot to the same extent be exploited by exporting. The loss of productivity gains due to reduced R&D and variety production comes on top of considerable terms of trade losses when export prices of variety-capital is linked to falling home prices. As a result, the effects of policy on long-run growth rates, consumption, and welfare are considerably dampened compared to the case with exogenous world market prices. Table 3 reports the results as percentage deviations from the reference path. In the alternative with domestic investment subsidies, the welfare and growth effects are even reversed compared to the reference path, and investment subsidies render welfare-deteriorating.

Table 3. Sensitivity to assuming that the export price of capital varieties evolves as the domestic price, percentage deviations from the reference path, long run effects

Policy alternative	R&D subsidy	Capital subsidy	Investment subsidy
Subsidy rate*	**5.20**	**1.25**	**4.14**
GDP	1.05	0.08	-2.05
GDP, growth rate**	0.03	0.00	-0.05
Welfare	0.10	-0.02	-0.95

*The exogenous rate in the sensitivity scenarios (per cent).
** Absolute deviation from the reference path.

4. Concluding remarks

Most previous studies conclude that current levels of R&D are inefficiently low from a macroeconomic perspective and that policy intervention is needed. However, there exist mechanisms that support the opposite conclusion, and whether and why R&D activity is suboptimal are country-specific questions that call for realistic macro-economic modelling. This study examines the case of small, open economies by means of a detailed CGE model that can account for interplays among markets and relevant endogenous and external mechanisms. After two decades of intensive research on the theoretical and empirical foundations of technological change, we believe that time is ripe for integrating the new knowledge within consistent, empirical macroeconomic frameworks that take short and long run effects of innovation policies into account. Until now, contributions have been scarce.

As expected, the clearest implication of the small, open economy case is that growth and welfare effects of subsidising innovation are much smaller than in applied analyses of larger, more closed economies. Much technological development is reaped only by absorption from abroad, and unless absorptive capacity is heavily reliant on domestic R&D or other domestic decisions, there are limits to growth and welfare impacts of domestic innovation policies.

Nevertheless, we find that innovation policy matters, and in the present setting it increases growth and welfare, in accordance with most econometric evidence. The policy design is, however, crucial for the results. In our small, open economy case, we find that most of the growth and welfare effects rely on the possibility of exporting new technology, thus the most efficient policy alternatives are those succeeding in promoting such exports. However, policies should also stimulate technology deliveries at home, due to market power inefficiencies and productivity potentials of variety in the domestic markets.

Our study indicates that the current policies directed towards private R&D are insufficient for reaching the proclaimed goal of the Norwegian government of an aggregate private R&D/GDP ratio of 2 per cent. We find, not surprisingly, that the most efficient instrument for reaching this goal is to intensify direct subsidies to private R&D. According to our computations, a 50 per cent increase in today's general R&D support increases the private R&D intensity to the desired level. However, importantly, higher R&D intensity and growth is not necessarily welfare enhancing. We find that subsidies towards capital formation generate lower R&D intensity and growth, but nevertheless they prove slightly welfare superior to a direct R&D subsidy. This is not a general result, but depends on the relative strengths of the existing inefficiences within the economy. Sensitivity tests do, however, indicate that the result is robust within the economic setting we study.

There are several potentials for adding features into the model that are empirically significant and relevant to the effects of innovation policies. First of all, the assumptions about the labour supply have crucial interactions with innovation policies. The present model assumes one national labour market with exogenous, unaltered supply among the policy alternatives. The welfare potential of innovation policy is restricted by limited resources, in particular the inflexible labour endowments. Expansion of the R&D industry is likely to attract mainly high-skilled labour. In reality, thus, the allocating effects of more innovation would be to crowd out skill-intensive industries, in particular, and not all labour-intensive activities as in the present framework. Distinguishing between different skill levels would be an interesting extension of the model. So would accounting for labour supply responses. As there are significant labour tax wedges in most developed economies, including Norway, stimulating labour supply would add an extra welfare-improving allocation effect of innovation policies. It would also introduce a significant difference between lump sum and other taxation and, thus, the possibility to study more realistic financing schemes than in the present study. Other important questions related to labour supply is whether the educational composition of the labour force would respond to innovation policies, and how education policies would interact with innovation policies. All these interactions cannot be addressed within our present framework. Public R&D and its interaction with private R&D are other policy areas excluded in this study. All these would be interesting extensions.

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Appendix A

Table A.1: Production Activities

Other Products and Services
Manufacture of Metals
Polluting Transport Services
Non Polluting Transport Services
Research and development (R&D)
Transport Oils
Heating Fuels
Variety-capital
Other Ordinary Machinery
Building of Ships, Oil Drilling Rigs, Oil Production Platforms etc.
Construction, excl. of Oil Well Drilling
Ocean Transport - Foreign, Services in Oil and Gas Exploration
Crude Oil
Natural Gas
Pipeline Transport of Oil and Gas
Production of Electricity
Wholesale and Retail Trade
Government Input Activities

The model structure of firm and household behaviour

When firm notation *i* is suppressed, all variables in the equation apply to firm *i*. Subscripts denoting industry is also suppressed for most variables. Subscript 0, -1, or *t* denote period. When period specification is absent, all variables apply to the same period. Compared to the exposition in Section 2, we disregard inputs of intermediate goods. In consumption, *i* denotes good *i*, *j* denotes CES composite *j*.

B.1 Production of final goods

(B.1) $$PV_0 = \int_0^\infty e^{-rt}\left(\pi_t - P_t^J J_t\right)dt = \int_0^\infty e^{-rt}\left(\pi_t - P_t^K K_t\right)dt + P_t^J K_0$$

(B.2) $$\pi = P^H X^H + P^W X^W - wL$$

(B.3) $$\left[\left(X^H\right)^\rho + \left(X^W\right)^\rho\right]^{1/\rho} = \left[f\left(L\tau, K\tau\right)\right]^s$$

(B.4) $$C = c\left[\left(X^W\right)^{1/s} + \left(X^H\right)^{1/s}\right]$$

(B.5) $$\pi' = P^H X^H - c\left(X^H\right)^{1/s} + P^W X^W - c\left(X^W\right)^{1/s}$$

(B.6) $$P^H = \frac{c}{s}\left(X^H\right)^{\frac{1-s}{s}}$$

(B.7) $$P^W = \frac{c}{s}\left(X^W\right)^{\frac{1-s}{s}}$$

(B.8) $$s = 1/\rho$$

(B.9) $$K = \left[\delta_{kM}\left(\frac{K_M}{\delta_{kM}}\right)^{\left((\sigma_k - 1)/\sigma_k\right)} + (1-\delta_{kM})\left(\frac{K_V}{(1-\delta_{kM})}\right)^{\left((\sigma_k - 1)/\sigma_k\right)}\right]^{\left(\sigma_k/(\sigma_k - 1)\right)}$$

(B.10) $$K_V = \left[\sum_{i=1}^{R}\left(K_{Vi}\right)^{(\sigma_{kv}-1)/\sigma_{kv}}\right]^{\sigma_{kv}/(\sigma_{kv}-1)}$$

B.2 Production of ideas

Eqs. (B.1) and (B.8) apply to firms within the R&D industry. In addition, the following structure describes the industry:

(B.2') $$\pi = P_R^H X_R^H - wL$$

(B.3') $$X_R^H = [R]^{s_1} \left[f\left(L\tau, K_M\tau\right)\right]^s$$

(B.4') $$C = \frac{c}{(R)^{s_1/s}} \left[X_R^H \right]^{1/s}$$

(B.11) $$R = R_{-1} + X_R^H$$

(B.5') $$\pi' = P_R^H X_R^H - \frac{c}{(R)^{s_1/s}} \left(X_R^H \right)^{1/s}$$

(B.6') $$P_R^H = \frac{c}{s(R)^{s_1/s}} \left(X_R^H \right)^{\frac{1-s}{s}}$$

B.3 Production of capital varieties

For firms producing capital varieties, eq. (B.2) applies, in addition to the following:

(B.1'') $$PV_{i0} = \int_0^\infty e^{-rt} \left(\pi_{it} - P_t^K K_{it} \right) dt - P_{R0}^H + P_0^J K_{i0}$$

(B.3'') $$\left[\left(X_{ki}^H \right)^\rho + \left(X_{ki}^W \right)^\rho \right]^{1/\rho} = \left[f\left(L_i\tau, K_{Mi}\tau \right) \right]^s$$

(B.4'') $$C_i = c\left[\left(X_{ki}^W \right)^{1/s} + \left(X_{ki}^H \right)^{1/s} \right]$$

(B.5'') $$\pi_i' = P_{ki}^H \left(X_{ki}^H \right) X_{ki}^H - c\left(X_{ki}^H \right)^{1/s} + P_k^W X_{ki}^W - c\left(X_{ki}^W \right)^{1/s}$$

(B.6'') $$P_{ki}^H = m_{ki} \frac{c}{s} \left(X_{ki}^H \right)^{\frac{1-s}{s}}$$

(B.12) $$\varepsilon_{ki} = -\frac{\partial X_{ki}^H}{\partial P_{ki}^H} \frac{P_{ki}^H}{X_{ki}^H}$$

(B.13) $$m_{ki} = \frac{\varepsilon_{ki}}{\varepsilon_{ki} - 1} = \frac{\sigma_{kv}}{\sigma_{kv} - 1}$$

(B.7") $$P_k^W = \frac{c}{s}\left(X_{ki}^W\right)^{\frac{1-s}{s}}$$

(B.14) $$P_{kv} = \left[\sum_{i=1}^{R}\left(P_{kvi}\right)^{(1-\sigma_{kv})}\right]^{1/(1-\sigma_{kv})}$$

(B.15) $$P_{R0}^H = \int_0^\infty e^{-rt}\left(\pi'_{it}\right)dt$$

B.4 Consumer behaviour

(B.16) $$U_0 = \int_0^\infty u\left(d_t\right)e^{-\rho t}dt$$

(B.17) $$u(d_t) = \frac{\sigma_d}{\sigma_d - 1} d^{\left(\frac{\sigma_d - 1}{\sigma_d}\right)}$$

(B.18) $$W_0 = \int_0^\infty PD_t d_t e^{-rt} dt$$

(B.19) $$d_t = \left[\lambda \cdot PD_t\right]^{-\sigma_d}$$

(B.20) $$D_t = d_t (1+n)^t$$

(B.21) $$D_{it} = \omega_{i.0}\left(\frac{PD_{jt}}{PD_{it}}\right)^{\sigma_j} \frac{VD_{jt}}{PD_{jt}}$$

(B.22) $$\frac{D_{t+1}}{D_t} = (1+n)\left(1+g^s\right)$$

B.5 Variable list

PV_0	The present value of the representative firm
π	Operating profit
P^J	Price index of the investment good composite
J	Gross investment
P^K	User cost index of capital composite
K	Capital composite
X^H	Output of final good firm delivered to the domestic market
X^W	Output of final good firm delivered to the export market
P^H	Domestic market price index of final good
P^W	World market price index of final good
W	Wage rate
L	Labour
τ	Factor productivity change through international spillovers
K_V	Variety-capital
K_M	Other ordinary capital
S	Scale elasticity
ρ	Transformation parameter between deliveries to the domestic and the foreign market
C	The variable cost function
c	Price index of the CES-aggregate of production factors
π'	Modified profit (the period-internal maximand of firms)
σ_k	Elasticity of substitution between variety-capital and other ordinary capital
δ_{kM}	Share of other ordinary capital in the capital composite
R	Accumulated number of capital varieties (and of firms and patents)
σ_{kv}	Uniform elasticity of substitution applying to all pairs of capital varieties
X_R^H	Production of new ideas
s_1	Elasticity of domestic spillovers
K_{Vi}	Capital variety *i*
P_{kvi}	User cost index of capital variety *i*
P_R^H	Price index of the patent
X_{ki}^H	Output of variety firm *i* delivered to the domestic market
X_{ki}^W	Output of variety firm *i* delivered to the export market
P_{ki}^H	Domestic market price index of variety *i*
P_k^W	World market price index of varieties
ε_{ki}	Domestic demand elasticity for capital variety *i*

m_{ki}	Mark-up factor for variety firm *i*
σ_{kv}	Substitution elasticity between two varieties
P_{kv}	User cost index of the variety-capital composite
U_0	Discounted period utilities of a representative consumer
d	Consumption of a representative consumer
ρ	Consumer's rate of time preferences
PD	Consumer price index
R	Nominal interest rate
W_0	Consumer's current non-human wealth + present value of labour income + net transfers
λ	Marginal utility of wealth
σ_d	Intertemporal elasticity of substitution
D	Aggregate consumption
N	Annual population growth rate
D_i	Demand for consumer good *i*, ,
VD_j	Aggregate expenditure on CES aggregate *j*
$\omega_{i.0}$	Budget share of good *i* in CES aggregate *j* in period 0
σ_j	Elasticity of substitution between the two consumer goods in CES aggregate *j*
g^s	Growth rate

Figure B.1. The nested structure of the production technology

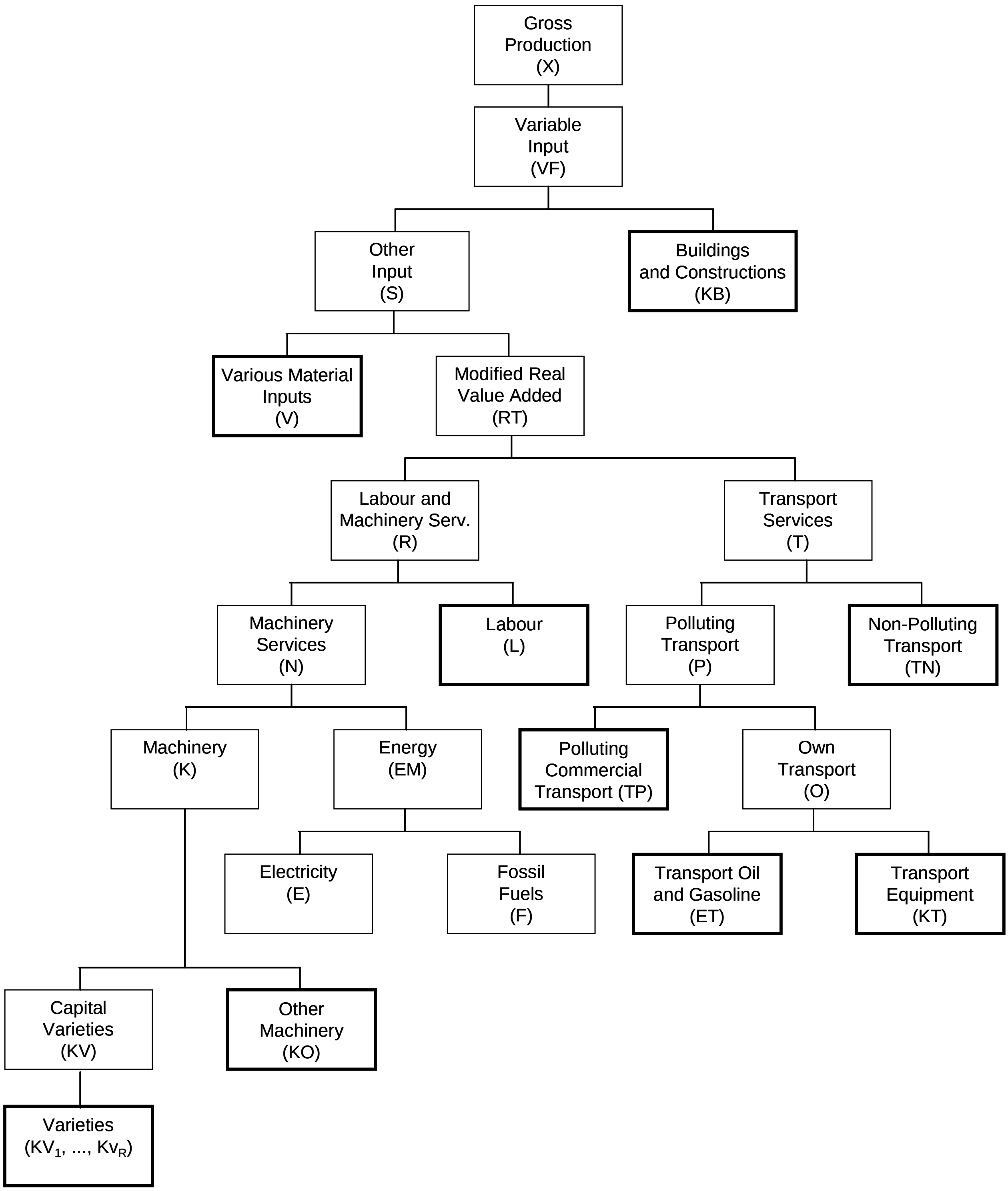
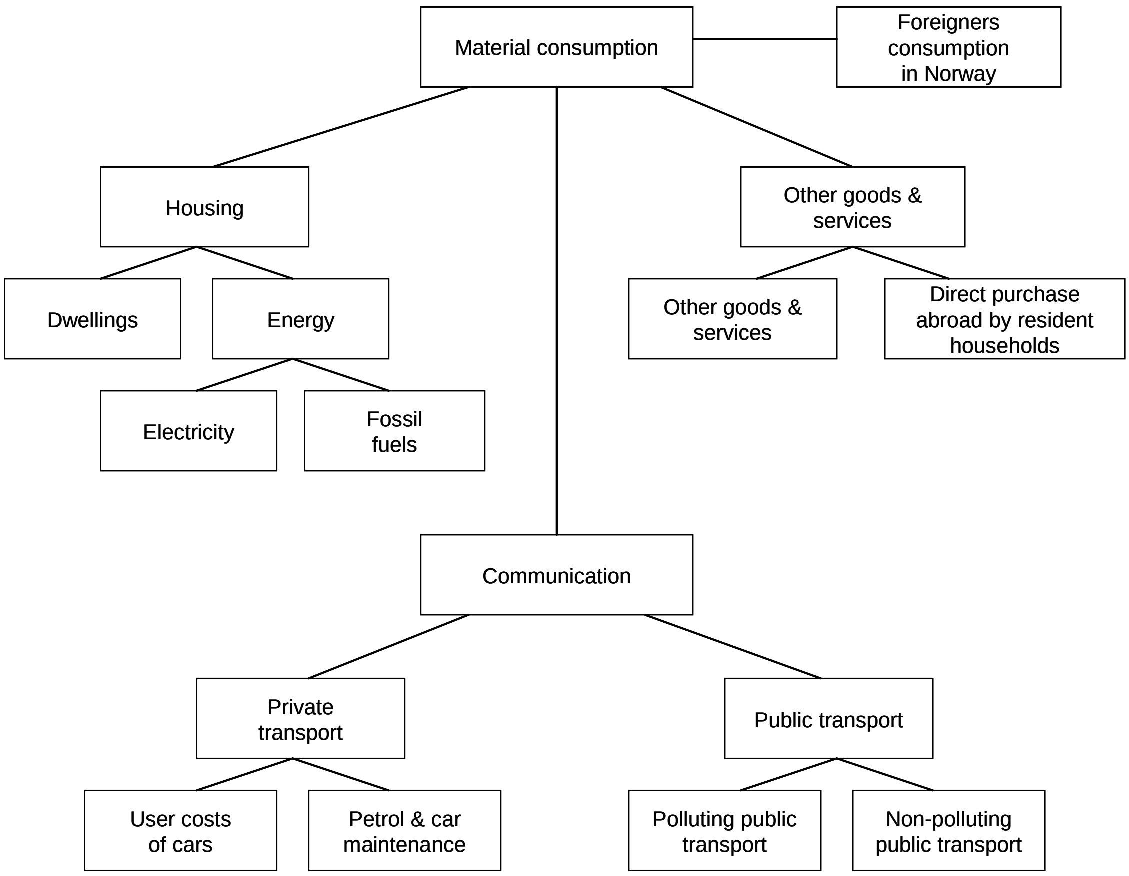


Figure B.2. The nested structure of consumption activities



Policy alternatives

Alternative 1 is a subsidy α_s towards production of new ideas/patents in the R&D industry. The representative firm's profit function is then given by

(C.1) $$\pi' = P_R^H (1+\alpha_s) X_R^H - \frac{c}{R^{s_1/s}} \left(X_R^H \right)^{1/s}.$$

From the first-order conditions of the firm's profit maximization we get the following marginal condition

(C.2) $$P_R^H = \frac{c}{(1+\alpha_s) s R^{s_1/s}} \left(X_R^H \right)^{\frac{1-s}{s}}.$$

Alternative 2 is a capital subsidy α_s towards the production of capital varieties. The representative firm's profit function is then given by

(C.3) $$\pi_i' = P_{ki}^H \left(X_{ki}^H \right)(1+\alpha_s) X_{ki}^H - c\left(X_{ki}^H \right)^{1/s} + P_k^W (1+\alpha_s) X_{ki}^W - c\left(X_{ki}^W \right)^{1/s}$$

The first-order condition for deliveries to the domestic market is given by

(C.4) $$P_{ki}^H = m_{ki} \frac{c}{(1+\alpha_s) s} \left(X_{ki}^H \right)^{\frac{1-s}{s}}$$

For deliveries to the export market the world market price equals marginal costs.

(C.5) $$P_k^W = \frac{c}{(1+\alpha_s) s} \left(X_{ki}^W \right)^{\frac{1-s}{s}}$$

Alternative 3 is a direct subsidy α_s towards domestic investments in capital varieties. This acts as a production subsidy towards only domestic deliveries. The representative firm's profit function is then given by

(C.6) $$\pi_i' = P_{ki}^H \left(X_{ki}^H \right)(1+\alpha_s) X_{ki}^H - c\left(X_{ki}^H \right)^{1/s} + P_k^W X_{ki}^W - c\left(X_{ki}^W \right)^{1/s}$$

The first-order condition for deliveries to the domestic market is given by

(C.7) $$P_{ki}^H = m_{ki} \frac{c}{(1+\alpha_s) s} \left(X_{ki}^H \right)^{\frac{1-s}{s}}$$

The domestic price is set as a markup over marginal costs and the subsidy α_s acts as a reduction in the marginal costs. For deliveries to the export market the world market price equals marginal costs.